ACCIDENTS WAITING TO HAPPEN
GROUND RESONANCE AND DYNAMIC ROLLOVER

Looking back over the history of our industry, we should all be grateful that the early pioneers persisted in making progress, despite the number of unexpected problems they encountered. (Perhaps we should be even more grateful that they did not have high-quality crystal balls.)

However, even after the dedicated work of those pioneers, some of the original problems are still with us. Two types of mishaps that have destroyed many helicopters before the vehicle has even lifted off the ground are ground resonance and dynamic rollover.

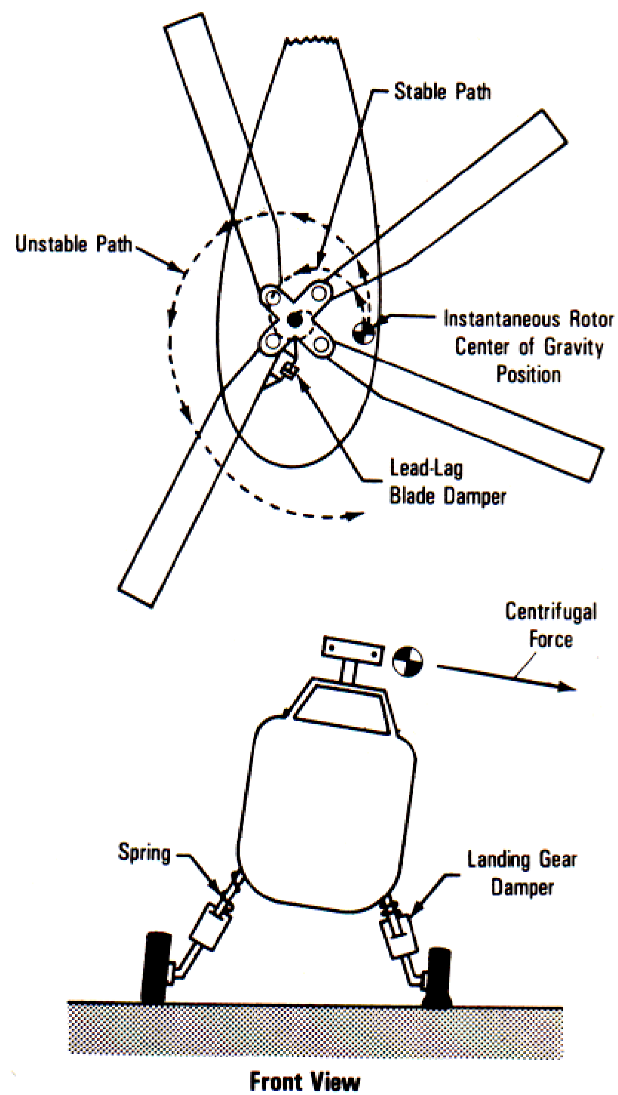
Ground resonance

Jaun de la Cierva, the inventor of the autogyro, gave later helicopter designers a rotor design with flapping hinges that made these machines feasible. He also gave them lead-lag hinges, which while solving some structural problems, has introduced another one.

If, for some reason, the blades move on their lead-lag hinge in such a way that their combined center of gravity (CG) is not on the center of rotation, a destructive oscillation may occur. In most flight conditions, such an unbalance will rapidly right itself as the individual blades sort themselves out. In this sorting-out process each blade leads and lags in such a way as to spiral the combined CG in toward the shaft where it belongs.

The potential problem exists if the aircraft is not airborne. A gust of wind, a sudden control motion, or a hard landing can displace the blades. The resultant whirling motion due to the offset centrifugal force may be just the right frequency to rock the airframe on its landing gear.

The figure illustrates the situation. Once that happens, the two motions get in step and instead of the CG spiraling gently inward, it spirals violently outward--producing a rotating force at the rotor hub that can shake the aircraft to pieces almost instantaneously.



Despite this dire possibility, ground resonance does not happen every time it has an opportunity--just often enough to scare everybody concerned.

The first recorded ground resonance accident was in the 1930s, when a Kellett autogyro apparently hit a rock while taxiing. This accident attracted the attention of scientists, who eventually produced a mathematical and physical understanding of the phenomenon. They found that ground resonance could be prevented with damping but that the damping must be both in the rotor around the lead-lag hinges and in the landing gear. Thus the most critical condition is just before the ship becomes airborne--since then the landing gear is extended and can provide little damping--although there is still a little stiffness to maintain a rocking motion.

As far as the pilot is concerned, prevention consists of making sure that all dampers are operational during the preflight inspection. If despite, this, the beginning of the oscillation is detected, the safest action is to either shut down or (if up to flying rpm) immediately take off. When composure is regained, the pilot should make the gentlest landing possible to a high-friction surface. This will produce damping in case the gear begins a scuffing action.

Rotors with high inplane stiffness and no lead-lag hinges are not susceptible to ground resonance and therefore do not need damping in their rotors or landing gear. Other hingeless rotors may or may not need dampers--depending on how high their inplane stiffness is.

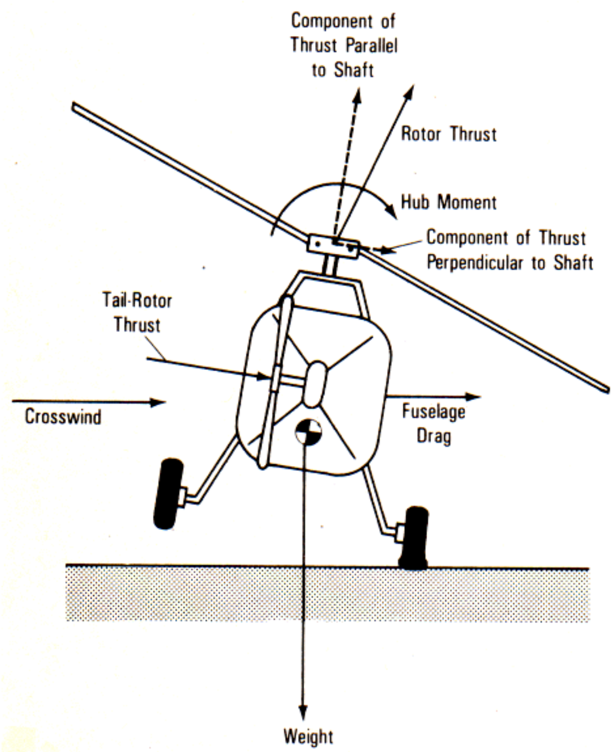
In some rare cases, the equivalent of ground resonance can occur in the air with a slingload. Operation in compliance with the operator's manual should allow the pilot to avoid this situation but jettisoning the load is a sure--if drastic--cure.

Dynamic rollover

In flight, high bank angles are of no great concern because control around the roll axis is usually where the helicopter is at its best. On the ground, however, even a moderate bank angle can be disastrous if it is enough to tip the machine over.

The primary upsetting helicopter moments are due to rotor flapping, with the resultant tilted thrust vector and hub moments as shown below.

Start of a Possible Rollover



Rear View

The flapping may be due to the pilot inadvertently putting in some lateral cyclic pitch while the ground restrains the landing gear. Starting in a crosswind may also be a factor. Besides the rolling moment due to the wind on the fuselage, the lateral flapping which would be negligible at flat pitch, becomes significant as thrust is increased for takeoff as the non-uniform aerodynamics produce flapping--sometimes referred to as "blowback." In addition, as the shaft is tilted against the springiness of the landing gear, the increased angle of attack generates even more flapping. Thus, if the pilot is not compensating for the disc tilt with cyclic pitch, he will find the upsetting effects increasing at the same time that the restoring effects are decreasing. Sometimes tail rotor thrust also contributes. From whatever source, the helicopter will want to pivot about the point of contact.

The moment that keeps the helicopter from tipping over comes from the weight acting between the two wheels or skids. As the helicopter rolls on its landing gear, this stabilizing moment diminishes; it goes to zero if the ship ever rises on one wheel far enough to put the CG right over that wheel. If the helicopter is sitting on slope, it already has a reduced restoring moment and a lateral CG position (perhaps caused by fuel sloshing). A narrow landing gear tread or a rolling deck compounds the problem.

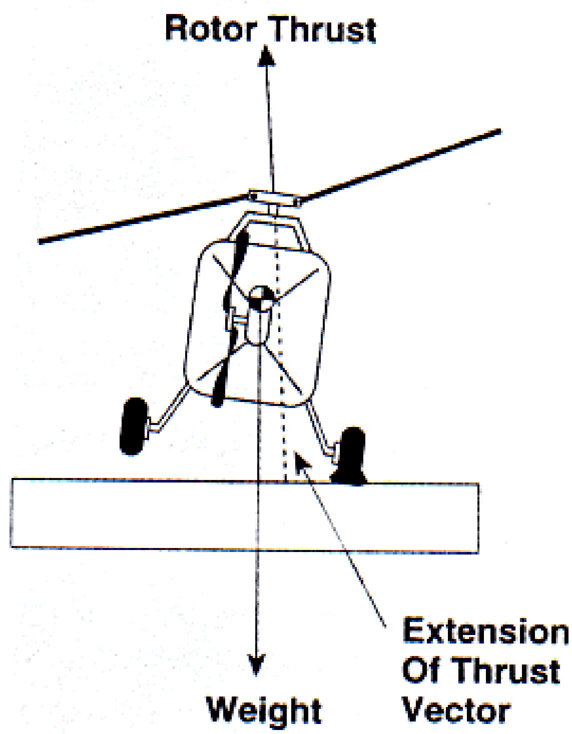
In a normal takeoff of most single-rotor helicopters, one landing gear comes off the ground first, but, since this happens just as the helicopter becomes airborne, this action is not associated with a rollover. If, however, one landing gear comes off the ground with only partial thrust on the rotor, a rollover may be starting. In this situation, the pilot might try to hurry the takeoff by raising the collective. This is usually a mistake since the increased thrust in the same direction results in an increase in the upsetting moment.

If some rolling velocity builds up, it represents a large quantity of momentum proportional to the square of the distance from the pivot point to the CG. Reducing this momentum to zero with lateral flapping takes some time. Meanwhile the helicopter is rolling closer and closer to its fallover angle. Thus even a small delay can result in an accident. This time dependency is why the phenomenon is called "dynamic rollover."

This explanation can be carried one step further by pointing out why even quickly using opposite cyclic pitch may not be good enough. The next figure shows the rotor flapped in the right direction to produce a restoring effect.

If the maximum flapping angle is less than required to point the thrust rotor vector outside the point of contact, thrust only makes the situation worse. The lateral flapping for most modern helicopters is limited to about 10°. No helicopter that I know has such a narrow landing gear tread that a roll could be stopped by using full opposite stick and up collective.

Trying To Stop Roll With Lateral Flapping



Rear View

A reduction of collective pitch to get both gear firmly on the ground is the accepted cure for a dynamic rollover but this should be done gently. If the helicopter is dropped too fast, it might bounce on the gear that was in the air and start rolling in the other direction.

Although pilot distraction or inattention is usually required to set up the conditions of a dynamic rollover, some accidents have occurred when a liftoff was attempted with one landing gear still stuck by mud, ice, or a tiedown.

The ability of the pilot to roll a helicopter over on the ground is enhanced by very stiff hingeless rotors, since even at flat pitch a little out-of-trim cyclic pitch can produce a high, upsetting hub moment. In the Lockheed AH-56 Cheyenne, to discourage the pilot from holding the stick off-center, a device was installed that stiffened up the control centering springs whenever the aircraft had its full weight on the landing gear. The device was de-activated on takeoff as “squat switches” sensed the partial extension of both landing gear oleos.

From *Rotor and Wing*, October 1981 and December 1994 and Chapter 15 of *Helicopter Aerodynamics*